ZEOLIGHTS: Photonic Emitters in Extra-Large Pore Zeolites for Tailored Optical Materials

Zeolites offer molecular-scale porosity and exceptional thermal and chemical stability, making them ideal hosts for diverse emitters, including noble metal nanoclusters, semiconductor quantum dots (QDs) (e.g., perovskites), and organic dyes [1–3]. The zeolite's confining structure allows control of the emitter's local geometry, charge, and dielectric environment, modulating its spectral response. These capabilities have been reported for spatial isolation of emitters, preventing aggregation and quenching (mainly in dyes), while enhancing quantum efficiency and environmental stability. These improved properties have been exploited in solid-state lighting, gas sensing, optical encoding, and bioimaging [4].

Despite previous advances, conventional zeolites impose intrinsic limitations due to their small pore size: they cannot accommodate bulky photoactive species and only allow low emitter concentrations to avoid aggregation-induced quenching. Furthermore, their narrow channels hinder spatial control over emitter distribution, essential for photophysical processes such as Förster Resonance Energy Transfer (FRET), where precise donor–acceptor distances are critical, or metal-enhanced luminescence, which relies on optimized emitter–metal interactions.

ZEOLIGHTS overcomes these constraints by exploiting a new generation of zeolites with 3D networks of extra-large pores and exceptional structural stability, enabling encapsulation of larger and more versatile emitters in well-defined configurations. The expanded cavities can host a broader variety of emitters—metal clusters, bulky dyes, and QDs—within a structurally rigid and chemically inert matrix. This allows the design of hybrid systems with tunable spatial arrangements and inter-emitter distances, enabling systematic investigation of photophysical processes such as FRET, amplified emission, and plasmon-mediated luminescence with improved stability and efficiency (expected QY above 60%) [1]. While host–guest photophysics in zeolites is a mature discipline, ZEOLIGHTS explores a novel concept: integrating dyes, small quantum dots, and metal clusters within extra-large pore zeolites—an underexplored frontier that merges synthetic innovation with emerging photonic functionalities.

The project builds on the expertise of Camblor's group in synthesizing stable extra-large pore zeolites [5] and Blanco's group in photonic materials design and advanced optical spectroscopy. Together, the collaboration will enable right-on-time novel exploration of complex photophysical phenomena within state-of-the-art zeolite hosts. The project integrates rational design and advanced characterization to establish modular platforms for photonic zeolite-based materials, contributing to the development of energy-efficient, multifunctional optical technologies.

References

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Integración en el plan estratégico, complementariedad de temáticas, sinergias, fondos y equipamiento disponibles

ICMM STRATEGIC PLAN: The ZEOLIGHTS proposal fits mainly with A3 line, where "*the design, synthesis and fabrication of materials with tailored properties are paramount*". Likewise, the proposal also fits A1 line, ("*new materials with focus on optoelectronics, photonics"*). In addition, positive outcomes will also impact line A2 (where nanostructures involving semiconductors are contemplated) and in A5 line, to improve the well-known lack of stability of NIR dyes for bioimaging. In addition, this line of work benefits from synergies with ICMM's transversal hubs, such as the artificial intelligence laboratory (for screening host-guest combinations by machine learning) and the nanofabrication platform (for the potential integration of these emitters in devices).

SYNERGY: Camblor possesses extensive expertise in designing zeolite structures with varying pore sizes and controlled composition/defect chemistry, enabling precise host–guest interactions, and has recently developed state-of-the-art zeolites, whose properties should be exploited at the ICMM [1,2]. Blanco brings deep knowledge in advanced optical characterization techniques, with wide experience on enhancing light emission across diverse photonic materials [3,4]. This project represents a timely opportunity to consolidate a strategic internal collaboration between the two PIs, bringing together complementary expertise in zeolite design and photonic materials, and combining advanced host engineering with optical emission control in hybrid nanosystems. As a first outcome of this collaboration, the PIs have co-authored a joint publication currently under review [5], providing concrete evidence of the project's viability and the strong scientific alignment between both teams.

FUNDING: Both PIs have received continuous funding from the AEI over decades (two running projects), demonstrating a sustained trajectory of scientific excellence and competitiveness within national research programs, ensuring support for this PhD. Importantly, both PIs have supervised PhD students throughout their careers, evidencing supervision capabilities for this proposal.

INFRASTRUCTURE: The PIs have access to the full experimental infrastructure required for the successful execution of the project, including a dedicated laboratory for zeolite synthesis and a laser spectroscopy facility with instrumentation for steady-state and time-resolved measurements across the visible and near-infrared ranges. Complementary characterization will be enabled by a dedicated quantum yield setup to be acquired by ICMM (acquisition in progress). This new facility will be a valuable tool within the framework of this proposal. Advanced characterization includes regular visits to synchrotron facilities (ALBA, ESRF), a strong asset for the PhD student's training and development.

References

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